SCIENCE

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MSS. intended for publication and books, etc., intended for review should be sent to the responsible editor, Professor J. McKeen Cattell, Garrison-on-Hudson, N. Y.

*A NEW GAS.**

The purpose of this purely preliminary paper is to announce the discovery of a new gas, presumably elementary, and possessed of some extraordinary properties. It is a constituent of the atmosphere and is occluded by many substances. Its chief characteristic thus far ascertained is enormous heat conductivity at low pressures. In order to appreciate this phenomenon it is necessary to consider the heat conductivity of some of the well-known gases.

A year ago I had the honor to read before this Section a paper on the transmission of heat by gases, illustrated by numerous curve sheets showing the heat conductivity of several gases at all pressures from atmospheric down to the best vacuum obtainable; also an allied paper on the measurement of small gaseous pressures. Abstracts of these papers appear in the current volume of Transactions, and their full text may be found in the *Philosophical Magazine* for January, 1898, and November, 1897, respectively.

The apparatus used for the described experiments in heat transmission consisted in part of a long-stemmed thermometer hanging in a long-necked glass bulb, the bulb of the thermometer being in the center of the glass bulb. Two bulbs were used for different experiments; the larger one 112 mm. in diameter, the smaller one only 20 mm. A tank of water and crushed ice under the bulb was adapted to be raised when desired, so as to immerse the bulb in the cold mixture. The neck of the bulb was connected with an air pump capable of reducing the internal pressure to a very small fraction of a millionth of atmospheric pressure; also with an elaborate pressure

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* Read before the American Association for the Advancement of Science, August 23, 1898.

gauge adapted to measure small pressures with very great precision, and a barometric gauge for measuring larger pressures.

In using this apparatus the gas to be tested was introduced at atmospheric pressure; the ice tank was raised, and the falling temperature of the thermometer, which could lose heat only by radiation, conduction and convection through the surrounding gas, was observed through a telescope. The time required for the temperature to fall through a given range, usually from 15° to 10° Centigrade, was carefully noted. Then the ice tank was lowered, permitting the thermometer to regain the temperature of the laboratory; some of the gas was pumped out, and the cooling of the thermometer again observed at this reduced pressure. This process was repeated many times, until the pressure was reduced to the lowest point attainable.

The results obtained with each gas were plotted in a curve showing its heat conductivity at all pressures from atmospheric down; the ordinates representing the reciprocals of the time of cooling in seconds, while the abscissas represented the pressure.

The present chart shows curves representing the heat conductivity of several gases, from fifty millionths of atmospheric pressure downward. The data for all of these, except the helium curve, are taken from last year's paper; but the scale is different.

I am indebted to Professor Ramsay for the helium used in obtaining the curve here shown.

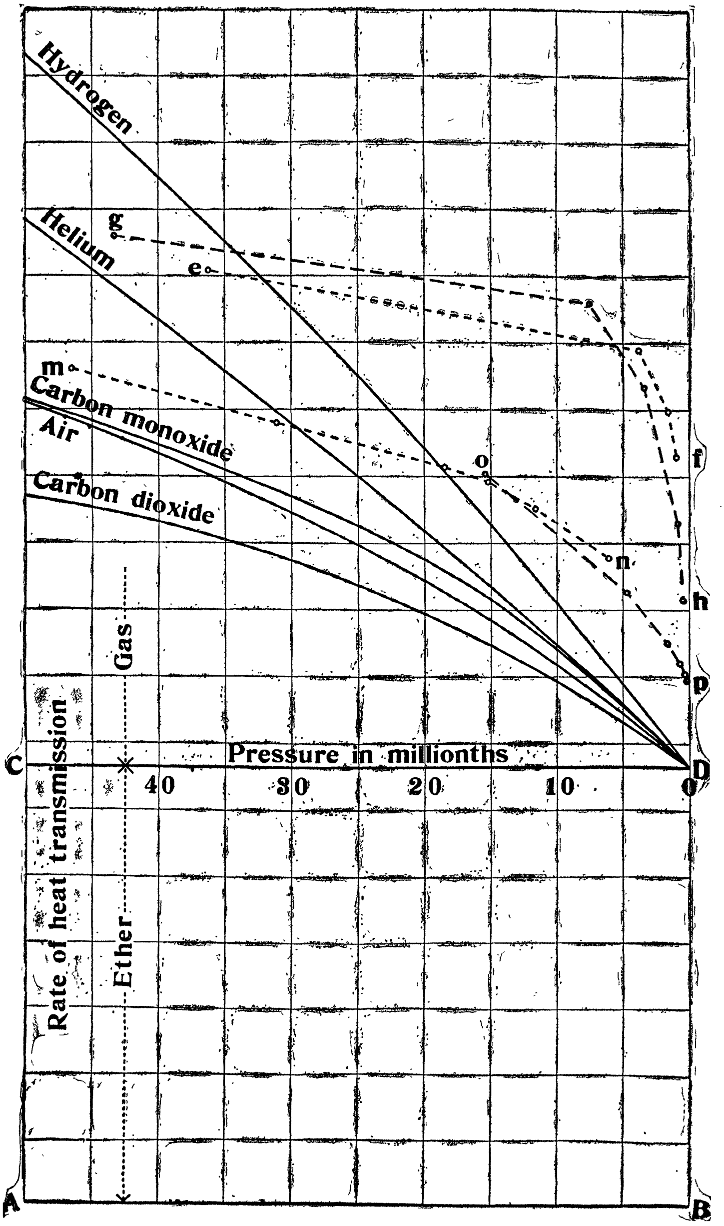
The ordinates of each curve measured from A B as a base line represent the total rate of heat transmission by the ether and the gas at the pressures indicated by the abscissas, while ordinates measured from the line C D represent the heat transmitted by the gas alone.

It will be observed that the curves of all the gases named vanish together at the point of zero pressure D. Repeated experiments have shown this condition to be always strictly true within the narrow limits of errors of observation, provided that, before the introduction of the gas to be tested, the whole apparatus has been kept highly exhausted for several days; or, better still, has been heated several hours by means of air and water baths, while kept exhausted. Without one of these precautions I was never able to get any gas curve quite down to the point D, for reasons which will appear. The point D represents a period of three hundred seconds required for the temperature of the thermometer to fall from 15° to 10°, with the pressure of the surrounding gas reduced to one twenty-millionth or less.

A very brief account of the circumstances which led to the discovery of the new gas may not be out of place. I had long been engaged in high vacua experiments, and had observed that glass apparatus, when highly exhausted and heated, evolved gas for an indefinite length of time, rapidly at first, then slower, but never stopping until the temperature was reduced. On cooling, rapid reabsorption always took place, but was never complete; indicating that two or more gases had been evolved by heating, one of which was not absorbed by cooling. In other words, the absorption was selective. The truth of this conclusion was abundantly demonstrated subsequently. However, the percentage of reabsorbed gas was so large that I used a small quantity of pulverized glass in several experiments to absorb a part of the residual gas after the highest attainable exhaustion was reached. The pulverized glass was always lead glass like that of the apparatus, and was heated nearly red-hot for several hours before and during the final exhaustion.

During these experiments a curious phenomenon was noted—the pulverized glass lost its snowy whiteness. This I thought must be due to reduction of some of its lead, probably by hydrogen evolved on heating. If so, I argued that the hydrogen must have been absorbed from the atmosphere since the manufacture of the glass; and its presence in the glass, if proved, would be a long step toward proving the normal presence of hydrogen in the atmosphere.

Chart Showing Relative Heat Conductivity of Gases.



Following the line of experiment thus

suggested, I prepared a quantity of pulverized soda glass free from lead and placed about 120 grams of it in a large combustion tube connected with the apparatus already described. The glass was made from an old stock of tubing, and was of such a degree of fineness that it all passed through a sieve of 90 meshes to the linear inch, but would not pass through a 140-mesh sieve. The combustion tube was adapted to be heated by a gas furnace with automatically regulated gas supply, so as to be maintained at any desired temperature.

While prepared to make analysis, in the usual way, of the gas evolved by the pulverized glass in case it appeared in sufficient quantity, I relied chiefly on its heat conductivity for the detection of any large proportion of hydrogen in the last few millionths, not being prepared at that time for spectroscopic examination; and thinking that, perhaps, some hydrogen might be evolved in the last stages of exhaustion before heating, I tested the conductivity of the residual air from time to time as the preliminary exhaustion progressed.

When the exhaustion approached a good vacuum an astounding phenomenon developed. At 36 millionths pressure the residual gas conducted heat twice as well as air, and nearly as well as hydrogen; at 3.8 millionths it conducted seven times as rapidly as hydrogen; at 1.6 millionths, fourteen times, and at .96 of one millionth, twenty times as rapidly. These results are plotted in the curve *e f*. I did not carry the exhaustion lower than .96 M. At this pressure the time of cooling of the thermometer from 15° to 10° was only 177 seconds, while pure hydrogen would have required 288 seconds.

Evidently a new gas of enormous heat conducting capacity was present, mixed with the last small portion of air. It must have come from the pulverized glass, and probably formed only a small fraction of the mixture. The last cc. of gas pumped out was collected, and upon subsequent analysis of it nothing but air was found.

The discovery of the new gas, as above outlined, was made nearly a year and a half ago, on March 10, 1897. On the following day the pressure had increased to nearly five millionths; while the time of cooling of the thermometer, instead of diminishing as usual with increase of pressure, had raised from 177 seconds to 245 seconds, showing that the new gas had largely disappeared. This was subsequently found to be due to absorption by the phosphorus pentoxide used in desiccation.

Long continued moderate heating of the pulverized glass caused the evolution of some air, much carbon dioxide and hydrogen, some carbon monoxide, and more of the new gas. The selective absorption which occurred on cooling was confined almost wholly to the hydrogen and new gas. After further moderate heating and thorough exhaustion, I raised the temperature, continued the exhaustion, and got the results embodied in the curve *g h*, showing that much of the new gas was present; the conductivity at .38 millionth, the last station in the curve, being *twenty-seven times* that of hydrogen. Several days of high heating, with frequent exhaustion, failed to wholly deprive the pulverized glass of its new gas, though the output was greatly diminished. For this and other reasons, I believe that the new gas resides *in* and not simply on the surface of glass.

To make sure that the apparatus was not deceiving me, I sealed off the combustion tube, heated the vacuous parts several hours by means of air and water baths as before indicated, admitted air dried over phosphorus pentoxide, exhausted step by step, and got the data for the 'small-bulb' air curve shown here and in last year's paper. Evidently I had not been deceived about the presence of a new gas in the pulverized glass. I subsequently exposed this lot of glass several days to the atmosphere, spread out in a thin layer. When tested again after this exposure it yielded the new gas, both before and after heating, as freely as at first. This rejuvenation of pulverized glass by exposure to the air was fully confirmed with another lot made from common window glass, and in connection with the results obtained by the diffusion of air, hereafter described, leaves no room for doubt that the new gas is a constituent of the atmosphere.

Pulverized glass appears to begin evolution of the new gas as soon as the atmospheric pressure is reduced. In one case, while making a slow preliminary exhaustion, I tested the air which remained when the pressure was still 132 mm., and, to my great surprise, found it contained not only a trace, but a considerable quantity of new gas. The amount increased rapidly as the pressure was further reduced. This leads to the belief that finely pulverized glass gives up the greater part of its new gas on simple reduction of pressure to a low point, and without heating; somewhat as palladium gives up occluded hydrogen.

Several substances other than glass were examined, and nearly all found to contain the new gas. A specimen of old charcoal made from pine-wood sawdust by long exposure to a bright red heat yielded as was expected, comparatively large quantities of several gases when heated in vacuum. At some stages of the evolution these were rich in the new gas.

It would seem easy in such cases to remove the diluent gases by oxidation and absorption; but it is not. After making the necessary additions to my apparatus, I made many attempts of this kind. The reagents used were in large excess on account of the very small quantities of gas treated; so that some of the observed results may have been due to impurities. Cupric oxide and lead chromate evolved gases of their own almost indefinitely on high heating in vacuum, and then freely absorbed carbon dioxide and moisture at a lower temperature. Soda-lime dried in vacuum in presence of phosphorus pentoxide was almost indifferent to carbon dioxide. All the reagents named, especially phosphorus pentoxide, absorbed the new gas; and all but the latter give it up again on heating.

A specimen of very fine white silicious sand, when heated in vacuum, gave a large quantity of gas consisting principally of hydrogen and hydrocarbons, with a considerable amount of the new gas. Some of this mixture was exposed successively to the action of red-hot cupric oxide, soda-lime and phosphorus pentoxide. By this treatment the gases were reduced to less than three per cent. of their former volume. The residue was not very rich in the new gas, because of the absorption of the latter by the soda-lime and phosphorus pentoxide, as I afterwards learned; but I have shown the curve *o p* of its heat conductivity, because the pressure was carried to a lower point than in any other case. At the last station in the curve, representing a pressure of .12 of a millionth, the conductivity was equal to that of 5.1 millionths, or forty-two times as much hydrogen. From this it seems reasonably certain that the curve *e f*, if carried to as low a pressure, would have shown a conductivity at least a hundred times greater than hydrogen. And yet the new gas in that experiment must have been very far from pure on account of the continuous evolution of ordinary gases, as shown by the rise of pressure and loss of conductivity during the next few hours.

It will be observed that when the new gas was present the form of the conductivity curves was very different from those of the known gases, the effect of the new gas becoming more prominent as the pressure was reduced. I do not doubt that this was due to the interference of the heavier and slower moving molecules of the ordinary gases always mixed with the new gas. In last year's paper I described the same effect found in a mixture of carbon dioxide and hydrogen. When the new gas is obtained in a state of purity I expect to find its curve of heat conductivity similar to those of hydrogen and helium, but with immensely increased ordinates.

Believing that the new gas is very much lighter than air or hydrogen, and may therefore be separated from the atmosphere by successive diffusions, I have spent several months in experiments with this end in view. Quite recently my efforts have been crowned with most promising success. The difficulty has been to find a suitable porous septum; one free from holes, and sufficiently fine-grained to prevent more than a very slow passage of air, while a considerable surface is exposed to the atmosphere on one side, and to a fairly good vacuum on the other. Many substances were tried. India-rubber gave encouraging results, but was capricious and very slow. The best results have been obtained with porous porcelain having its superficial pores nearly closed by suitable treatment. A tube of this kind, closed at one end, and exposing rather more than five square inches of surface to the air, was connected with the apparatus, and the whole kept exhausted to a pressure of 1.3 mm. About 19 cc. of gas was diffused per hour. After 36 hours the diffusion tube was shut off, the exhaustion continued, and data for the curve *m n* obtained. It was found impracticable to carry the exhaustion below six millionths, because of the presence of moisture, which interfered with the action of the pump, no desiccating agent being used. As both phosphorus pentoxide and soda-lime absorb the new gas they cannot be used for desiccation. If the exhaustion had been carried as far as in the curve *o p* it is probable that a higher conductivity than in that curve would have been shown; *i. e.,* a conductivity more than 42 times that of hydrogen, or something like a hundred times that of air. Here we have the heat conductivity of air at very low pressure, increased something like a hundred-fold by one diffusion. I have not yet tried a secondary diffusion, but feel confident that successive diffusions of air will afford a practicable means of obtaining the new gas in a state of approximate purity.

Now let us discover, if possible, the meaning of the extraordinary heat conductivity of the new gas. I have tabulated the molecular weight, density, specific heat, mean molecular velocity and heat conductivity of hydrogen, helium, carbon monoxide, air and carbon dioxide, which are the known gases represented in the curve chart. For easy comparison, I have taken not only the density, but the specific heat, mean molecular velocity and heat conductivity of hydrogen as unity. The similarity of values in the fifth and sixth columns, for molecular velocity and heat conductivity, is striking. On the chart the curves for carbon monoxide, air and carbon dioxide are evidently too high to correspond well with the relative values of molecular velocity in the fifth column; but these curves represent only the last 50 millionths of the complete curves. By following these back to 500 millionths, which is still a rather small pressure, and taking their values at intervals of 10 millionths from no pressure upward, we obtain as a mean of all these values for each gas the quantities shown in the sixth column. These agree fairly well with the molecular velocities.

I offer the suggestion that the relatively high conductivity of the last three gases at the low pressure shown in the chart is due to the dissociation of some of their molecules by unobstructed impact on the walls of the containing vessel; recombination being more and more retarded as the pressure is lessened, because the greater separation of the molecules reduces the frequency of collisions. Helium, perhaps because it is monatomic and therefore incapable of dissociation, has a nearly straight curve like hydrogen; and its ratio, given in the sixth column, varies but little throughout the whole range observed, which was more than a thousand millionths. I have taken the density of helium as 2, but Professor Ramsay finds it a little less than this when purified as far as possible by repeated diffusions. This makes its relative molecular velocity a little more than .71, and brings it still closer to the observed value of its heat conductivity.

Comparison of Gaseous Properties.

1 Gas	2 Molecular weight	3 Density D	4 Relative specific heat	5 Relative molecular velocity $\frac{1}{\sqrt{D}}$	6 Relative heat conductivity
Etherion	? 0.0002	? 0.0001	6000.?	100.?	100.
Hydrogen	2.	1.	1.	1.	1.
Helium	4.	2.	?.300	0.71	0.73
Carbon monoxide	27.8	13.9	0.072	0.27	0.33
Air	28.8	14.4	0.069	0.26	0.32
Carbon dioxide	43.8	21.9	0.064	0.21	0.21

From the foregoing, we may reasonably conclude that the heat conductivity of gases at low pressures, and their mean molecular velocities, are closely related. Hence, if we can learn the heat conductivity of an otherwise unknown gas we can form some idea of its mean molecular velocity; and from this, of its specific heat, density and molecular weight.

As before indicated, the heat conductivity of the new gas at very low pressure, even when mixed with a large proportion of other gases, is something like a hundred times that of hydrogen. I shall not be surprised to find the conductivity of the pure gas a thousand or more times greater than that of hydrogen; but let us be conservative, and for the present purpose call it a hundred times and see what follows. I have given it this value at the head of the sixth column.

If my inference that the heat conductivity and molecular velocity of gases are directly related is correct, then the molecular velocity of the new gas will be 100 times that of hydrogen, as shown at the head of the fifth column. As is well known, the mean molecular velocity of a gas varies directly with the square root of its absolute temperature, and is independent of pressure. The mean molecular velocity of hydrogen at the temperature of melting ice has been found by calculation to be 5,571 feet per second. Hence the mean molecular velocity of the new gas at the same temperature will be 557,100 feet, or more than 105 miles per second. At anything like this molecular velocity it would be quite impossible for a gas to remain in the atmosphere, *unless the space above also contained it.* A velocity of only about seven miles per second, if unchecked except by gravitation, would be sufficient to project a body from the earth permanently into space. Even at a temperature very close to absolute zero the new gas would have sufficient molecular velocity to escape from the atmosphere.

Again, inasmuch as the molecular velocities of gases vary inversely as the square roots of their densities, it follows from our assumption of its molecular velocity that the density of the new gas is only the ten-thousandth part that of hydrogen, as shown at the head of column 3. This is the hundred and forty-four thousandth part the density of air. It is generally believed that the gases of the atmosphere distribute themselves in the long run, each as though the others were absent. Hence the new gas must extend a hundred and forty-four thousand times as high as the heavy constituents of the air to bring about the same proportionate reduction of pressure, even if gravitation remained constant at all distances from the earth; but the restraining influence of gravitation on the expansion of the atmosphere diminishes as the square of the distance from the earth's center increases.

It is evident, therefore, without a mathematical demonstration, that the new gas, being present in the atmosphere, must extend indefinitely into space without great loss of pressure. This is only another way of stating the result of its assumed molecular velocity. Now, there is no doubt that the new gas exists in the atmosphere, though probably in very small proportion, perhaps much less than a millionth. Hence it seems really probable that it not only extends far beyond the atmosphere, but fills all celestial space at a very small pressure. In recognition of this probability, I have provisionally named it ætherion, or etherion, meaning 'high in the heavens.' Its symbol will naturally be Et.

I am aware that strong objections may well be raised to the hypothesis of an interplanetary and inter-stellar atmosphere; but I can see no escape from the conclusion I have drawn, if I am not mistaken in my premises.

The estimated relative specific heat of etherion appears at the head of the fourth column, based again on the assumed relative molecular velocity. In estimating the specific heat, I have not made it inversely proportional to the density, as would be required by Dulong and Petit's law, giving a value ten thousand times that of hydrogen; but have used the formula suggested by Professor Risteen in his work on 'Molecules and the Molecular Theory,' which requires that the product of the specific heat and molecular weight of gases shall vary with the number of degrees of freedom of their molecules. I have assumed as probably true that etherion is monatomic, with atoms possessing only three degrees of freedom.

Of course, the values I have estimated for the molecular weight, density, specific heat and molecular velocity of etherion are intended only to indicate the *order* of magnitudes we may expect to find on further investigation; and it must not be forgotten that they are based on two assumptions: first, that the heat conductivity of etherion is 100 times that of hydrogen; and second, that the ratio of heat conductivity and mean molecular velocity is the same for all gases. As before indicated, I expect to find the heat conductivity of etherion much higher than the value here assigned to it. If so, the real value of its other attributes will be still more startling than those here given. The second assumption, while by no means proved, seems at least a good 'first approximation' to the relation between heat conductivity and molecular velocity in gases.

There is some evidence that etherion is a mixture of at least two different gases. In the course of my experiments I have met with a great many specimens, obtained in various ways from various sources, but always mixed with a very large excess of other gases. Some specimens were almost wholly absorbed by the phosphorus pentoxide at first used for desiccation. Others were but partially absorbed; the absorption being very rapid at first, but in an hour or two dwindling to nothing, and leaving a residue of gases permanently showing, by their heat conductivity, the presence of a very considerable amount of etherion. Soda-lime absorbed etherion, but much less freely than phosphorus pentoxide, and gave it up again on heating. The gas thus recovered was but little, if at all, affected by phosphorus pentoxide.

In one experiment the gases evolved from ten ounces of pulverized window glass, both before and after heating, were passed through coarsely pulverized soda-lime and then over fresh phosphorus pentoxide. Not a trace of etherion remained. The same result was obtained when another lot of the silicious sand, already referred to, was used as the source of etherion.

I will venture the conjecture that etherion will be found to consist of a mixture of three or more gases, forming one or more periodic groups of new elements, all very much lighter than hydrogen. If this proves true I propose to retain the present name for the lightest one.

The transmission of radiant energy through space has always been to me a fascinating phenomenon, and I have indulged in much speculation concerning the ether—that mysterious something by means of which it is effected. The remarkable properties assigned to the ether from time to time, in order to account for observed phenomena, have excited my keen interest; but I have long entertained the hope that some simpler explanation of the mechanism involved will be found. To me, a less strain of the imagination is required in the assumption that, instead of a continuous medium, gaseous molecules of some kind, endowed perhaps with a mode or modes of motion at present unknown to us, are the agent of transmission; a gas so subtle, and existing everywhere in such small quantity, that it has escaped detection.

Perhaps the molecular hypothesis of the ether has proved so attractive to me because it supports the hope that we may sometime compass the perfect vacuum—a portion of space devoid of *everything*. Such a vacuum would be opaque to light, and gravitative attraction could not, I believe, act through it. It might afford a new point of view from which to study the profound mystery of gravitation; an *outside* point.

The late De Volson Wood (*Phil. Mag.*, Nov., 1885) considered the question of a gaseous ether mathematically, and deduced certain necessary properties of the hypothetical gas; chief among which were exceedingly small density and exceedingly high specific heat. Possibly we are about to find a gas which will fulfil the required conditions. It may be etherion, or its lightest constituent if it turns out to be a mixture. I venture to express the hope that etherion will at least account for some phenomena at present attributed to the ether.

On account of the presumably extreme smallness of its molecules as compared with those of glass, etherion probably passes through the latter when any considerable difference of pressure exists on opposite sides; though the passage may be very slow. It seems to be condensed or compressed in glass as before indicated, and may evaporate on the side of lower pressure, and be absorbed on the side of higher pressure, after the manner of hydrogen in passing through palladium. In my own experiments the heat transmission ascribed to the ether may be due to the presence of the new gas inside the bulb. A small fraction of a millionth would be sufficient, and this might escape detection by the pressure gauge, on account of the necessary compression in the gauge head causing absorption by the glass. Again, etherion must always be present to some extent in all 'vacuum tubes' (as well as in my own conduction bulb), on account of its long continued evolution from glass, and may be the medium of propagation of the Röntgen rays in the vacuum glass and air.

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EVER since the American Forestry Association was formed at Cincinnati, in 1882, the need of providing for forestry education has been a favorite topic at the meetings. There were those who wished to make the subject a part of the studies in the public schools, and others who desired the establishment of special schools, either separate or in connection with other educational institutions.

Fortunately for our public schools and over-burdened school teachers, who are struggling not always quite successfully to do justice to their legitimate functions, the schemes of our enthusiastic forestry reformers in the first direction have not matured beyond the introduction of an Arbor Day celebration, perhaps an occasional reading or talk, quite sufficient to call the attention of the young mind to the existence and significance of the subject.

Those who had higher aims and expected that the existence of technically educated foresters would pave the way to the application of their art contemplated, in their philanthropic desires, the sacrifice of the individual to the cause; for unless the students issuing from such forestry schools had other means of subsistence, their bread, if they could earn it, would hardly have been buttered through their knowledge of forestry.

It may be set down as an axiom that the employment of any specialist in a technical art comes, as a rule, when the economic conditions are ripe for such employment.

In the United States the exploitation of all resources has, as in every newly-settled country, been carried on without the technically educated specialist; until 1870 or thereabout mining engineers were a rarity, and the exploitation of the soil by agriculture has only just begun to be considered an art; agricultural rapine is still largely the practice, just as the natural resources of the forest are and will be still for some time the object of the lumberman's rapine.

When does the time for a change come? When does it become necessary to employ skill and art in the use of our resources? These are difficult questions to answer. In a general way, from the standpoint of the individual the answer can only be one, namely, 'when it pays;' a consideration of supply and market conditions determines for him when his financial interests are best subserved by the use of greater skill and knowledge. He may not always recognize the right moment, but it would be a profit calculation which would have to be employed to persuade him of its arrival.

From the standpoint of the community, the State, the financial consideration may be quite secondary; the interest in the preservation of certain favorable conditions may justify an expenditure, a sacrifice of the present for the sake of the future.

It was the recognition that such an interest existed which induced the State of New York to take a first step with regard to her forest resources thirteen years ago by ceasing to dispose of the forest lands which the State had unwillingly acquired through

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* Read before the American Forestry Association at Boston, August, 1898.